JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Evidence of a major gene influencing hair length and heat tolerance in Bos taurus cattle

T. A. Olson, C. Lucena, C. C. Chase, Jr. and A. C. Hammond

J Anim Sci 2003. 81:80-90.

Evidence of a major gene influencing hair length and heat tolerance in *Bos taurus* cattle[1,2,3]

T. A. Olson*[4], C. Lucena†, C. C. Chase, Jr.‡, and A. C. Hammond‡[5]

*University of Florida, Gainesville 32611; ‡USDA, ARS, Subtropical Agricultural Research Station, Brooksville, FL 34601; and †Universidad Centrooccidental "Lisandro Alvarado," Barquisimeto, Venezuela

ABSTRACT: Evidence was found that supports the existence of a major gene (designated as the *slick hair* gene), dominant in mode of inheritance, that is responsible for producing a very short, sleek hair coat. Cattle with slick hair were observed to maintain lower rectal temperatures (RT). The gene is found in Senepol cattle and criollo (Spanish origin) breeds in Central and South America. This gene is also found in a Venezuelan composite breed, the Carora, formed from the Brown Swiss and a Venezuelan criollo breed. Two sets of backcross matings of normal-haired sire breeds to Senepol crossbred dams assumed to be heterozygous for the *slick hair* gene resulted in ratios of slick to normal-haired progeny that did not significantly differ from 1:1. Data from Carora × Holstein crossbred cows in Venezuela also support the concept of a major gene that is responsible for the slick hair coat of the Carora breed. Cows that were 75% Holstein:25% Carora in breed composition segregated with a ratio that did not differ from 1:1, as would be expected from a backcross mating involving a dominant gene. The effect of the *slick hair* gene on RT depended on the degree of heat stress and appeared to be affected by age and/or lactation status. The decreased RT observed for slick-haired crossbred calves compared to normal-haired contemporaries ranged from 0.18 to 0.4°C. An even larger decrease in RT (0.61°C; $P < 0.01$) was observed in lactating Carora × Holstein F_1 crossbred cows, even though it did not appear that these cows were under severe heat stress. The improved thermotolerance of crossbred calves due to their slick hair coats did not result in increased weaning weights, possibly because both the slick and normal-haired calves were being nursed by slick-haired dams. There were indications that the slick-haired calves grew faster immediately following weaning and that their growth during the cooler months of the year was not compromised significantly by their reduced quantity of hair. In the Carora × Holstein crossbred cows there was a positive effect of slick hair on milk yield under dry, tropical conditions.

Key Words: Cattle, Coat, Hair, Heat Tolerance, Major Genes

 J. Anim. Sci. 2003. 81:80–90

Introduction

Ability to maintain homeostasis in deep body temperature (measured herein by rectal temperature, **RT**) under heat stress is a valuable asset for cattle in subtropical and tropical regions of the world. Although variation in heat tolerance among breeds and breed crosses has been studied for many years, relatively few efforts have been directed toward increasing our understanding of the mode of inheritance involved in heat tolerance. Variation in RT under heat stress has been studied as a quantitative trait in Australia and has been shown to have a low to moderate heritability (Turner, 1982; 1984; Mackinnon et al., 1991; Burrow, 2001).

Previous studies have shown that Senepol cattle are equal in heat tolerance to Brahman cattle (Hammond and Olson, 1994; Hammond et al., 1996) and that Senepol F_1 crossbreds with temperate breeds show heat tolerance comparable to those of Brahman and Brahman crossbreds (Hammond and Olson, 1994; Hammond et al., 1996; 1998). Observations of hair coat types of progeny of Senepol crossbred dams mated to temperate breed sires suggested that they were segregating into two categories, one group with very short, sleek hair coats like those of purebred Senepol and one group

[1]This manuscript is published as Florida Agric. Exp. Stn. Journal Ser. No. R-08666.

[2]Names of products are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product to the exclusion of others that may also be suitable.

[3]Appreciation is extended to E. J. Bowers, E. L. Adams, E. V. Rooks, M. L. Rooks, and the STARS staff for technical assistance and animal care.

[4]Correspondence: Dept. of Animal Sciences, P.O. Box 110910 (phone: 352-392-2367; fax: 352-392-7652; E-mail: olson@animal.ufl.edu).

[5]Present address: USDA-ARS-SAA, 950 College Station Rd., Athens, GA 30604-5677.

Received March 8, 2002.

Accepted September 16, 2002.

whose hair coats were typical of *Bos taurus* cattle. It was also observed that occasionally, Senepol calves were also born with hair coats like those of temperate cattle. These facts supported the concept that a major gene influenced the hair coats and heat tolerance of Senepol and other tropically adapted breeds of *Bos taurus* cattle. Therefore, the objectives of this study were to evaluate whether the short, sleek hair coat of Senepol and other breeds of cattle is controlled by a gene that segregates as a simple dominant and is responsible for increased heat tolerance. A further objective was to evaluate the effect of the gene on growth and milk yields.

Materials and Methods

Description of Trials

Two trials were conducted at the Subtropical Agricultural Research Station (***STARS***; lat 28°37′ N, long 82°22′ W) near Brooksville, FL, and a third at the El Tunal Dairy (lat 09°55′N, long 69°37′W), near Barquisimeto in the state of Lara in central Venezuela. The topography at STARS is composed of gently rolling hills; the highest elevation is 84 m. Average annual rainfall is 1,372 mm, with 54% occurring in June, July, August, and September. Average year-round temperature is 22°C, with chances of frosts occurring from November through March. The El Tunal Dairy is at an elevation of 682 m and is located in an extremely arid region of Venezuela.

The first STARS trial used Angus-sired progeny from Senepol × Hereford and reciprocal crossbred F_1 dams. Preweaning RT information of the Senepol × Hereford and reciprocal crossbred dams as calves and yearling heifers was described by Hammond and Olson (1994) and Hammond et al. (1996), respectively. Results from this first trial led to a second, larger study to evaluate Charolais-sired calves from Senepol × Angus F_1 dams. This second study also included calves from Brahman × Angus and Tuli × Angus F_1 dams. Management procedures and preweaning growth of the Angus crossbred F_1 dams were described by Chase et al. (2000), whereas their heat tolerance as yearlings was described by Hammond et al. (1998).

Trial 1. Twenty-eight calves from Angus sires and Senepol × Hereford or Hereford × Senepol F_1 dams were evaluated for hair length, RT, respiration rates, and weights in 1994. In addition, 10 purebred Angus calves were included as controls. Calves were from 5 to 8 mo of age at the beginning of the trial. Measurements were taken on three consecutive weeks during the hot summer months (July 17, July 26, and August 2) and during the cooler late fall (November 23, December 1, and December 7). Ambient temperature information for these dates is shown in Table 1. A subjective (1 to 4) system was used to evaluate hair length (**HCT**) on July 26. The lowest score (1) describes the extremely shorthaired, "slick" condition of purebred Senepol cattle and their F_1 crosses with temperate *Bos taurus* breeds. A striking difference between animals with a slick hair coat and that of a normal-haired contemporary of the same breed composition can be observed in Figure 1. Animals coded as HCT 1 give the same appearance and tactual sensation when stroked about the poll, neck, and lower tail as an animal recently clipped. Many Senepol F_1 crosses have slightly more hair on their polls than do purebred Senepol, but are still coded as a 1. The Angus-sired calves from Senepol × Hereford or reciprocal cross F_1 dams that were coded as 1 were considered to be slick-haired, and those coded 2 and higher were considered normal-haired in this analysis. All the Senepol × Hereford dams were slick-haired. Prior to all analyses of rectal temperature from all three trials, rectal temperatures were transformed by taking the log of the difference between the measured rectal temperature and 37.0°C in an attempt to normalize the data (Turner, 1982). The means reported are from similar analyses of untransformed data. Segregation data were evaluated using χ^2 analyses. Data were analyzed using the GLM procedure (SAS Inst., Inc., Cary, NC) of SAS. Separate analyses were conducted for each measurement date. The model used in the analyses of RT and respiration rate data included the fixed effect of breed type of calf (Angus, normal-haired, 25% Senepol and slick-haired, 25% Senepol), with age and order of working of the calf included as continuous covariates.

Trial 2. In this trial, preweaning HCT scores, clipped hair weights at weaning, pre- and postweaning weights, RT, and respiration rates reported as breaths/min (**BPM**) were collected on Charolais-sired calves from Brahman × Angus, Senepol × Angus, and Tuli × Angus F_1 cows. Pre- and postweaning information was obtained on calves born from 1997 through 1999 and preweaning information only was obtained from calves born in 2000. In addition, weaning hair scores were obtained on Charolais-sired calves from Senepol × Angus dams in 1996. Subjective HCT scores (1 to 4), respiration rates, RT, and temperament scores (1 = very docile, 5 = very aggressive; Hammond et al., 1996) were obtained in July and August on all Charolais-sired calves from 1997 to 2000. Clipped hair weights and weaning weights were collected in September of each year. Clipped hair weights were obtained to provide an objective evaluation of the quantity of hair that an animal possessed. A 175-cm^2 patch of hair was clipped from the right side of each animal over the ribcage area approximately 10 cm below the spine using electric clippers. If the area to be sampled was excessively soiled, a clean, adjacent area of the same size was clipped. Hair samples were collected, transferred into numbered plastic bags, and weighed. There was little variation in bag weight; an average bag weight was subtracted from each bagged sample weight to calculate net hair weights.

Following weaning in 1997 through 1999, all heifer calves were retained at STARS for evaluation of puberty and were evaluated for postweaning growth as well as heat tolerance in December and March following weaning. Steer calves during these same years were "backgrounded" in north-central Florida before being sent in November each year to a feedlot near Amarillo, TX, as a part of the University of Florida's "Pasture to Plate" program. Steers were fed until early June each year after having been on feed for 180 to 196 d and carcass characteristics were obtained. The same traits were evaluated through weaning on all calves in 2000, but no postweaning information was available. Ambient conditions, RT, BPM, and temperament scores were collected as described previously by Hammond et al. (1996; 1998). By having data collected in July and August as well as in December and March (heifers only), the animals were evaluated under conditions likely to be hot and humid, as well as during cooler conditions. Measurements of ambient conditions included temperature, black globe temperature (shaded and unshaded; Hertig, 1968; Buffington et al., 1981), and relative humidity. A temperature–humidity index (**THI**; West, 1994) was calculated for each date from the average ambient temperature and average relative humidity.

Ambient environmental conditions for both the pre- and postweaning studies of Charolais-sired calves from Brahman × Angus, Senepol × Angus, and Tuli × Angus F_1 cows are shown in Table 2. During all preweaning measurement dates in July and August, THI values of more than 80 (moderate heat stress) were observed. Even postweaning dates in December and January, with the exception of December 2, 1999, were above 72, an index value that has been associated with heat stress and reduced milk production in dairy cattle (West, 1994). Thus, the conditions under which these cattle were evaluated should have resulted in at least mild heat stress on all but one of the measurement dates.

Rectal temperature and respiration rate data were analyzed using the GLM procedures of SAS using a fixed model that included main effects of year, breed type of dam, contemporary pasture group, hair coat type within breed of dam, temperament score, and work order within working date. Similar models were used to analyze respiration rate in July and August.

Trial 3. This third, larger study was conducted in Venezuela, where data were collected from Carora, Carora × Holstein F_1, 75% Holstein:25 % Carora, and Holstein cows that were managed as dairy cows in the same management group under drylot conditions with access to shade. The Carora is a composite dairy breed that was developed in this area of Venezuela from crossing imported Brown Swiss bulls with local milking criollo cows. Phenotypically, hair coats of Carora cattle are very similar to those of Senepol. Holstein cows were mated by artificial insemination and natural service to more than 20 Carora sires to produce F_1 progeny. Holstein × Carora F_1 cows, in turn, were bred to Holstein sires, primarily of U.S. origin, to produce 75% Holstein:25% Carora progeny. A sample of lactating F_1 and 75% Holstein females at El Tunal were subjectively scored for HCT in early 1999. A subjective visual scoring system for HCT that coded animals with the short, sleek, "slick" haircoat of Senepol, most Carora, and many criollo breeds as 1, animals with hair coats like

Figure 1. Carora cows with slick (left) and normal hair coats.

Table 1. Ambient conditions—Trial 1

Date	Ambient temp, °C	Black globe temperature Shade, °C	No shade, °C	Relative humidity, %	Temp–humidity index
July 19	33.5	36.0	53.5	60.5	85.1
July 26	27.2	34.3	29.0	82.0	77.2
August 2	32.9	33.5	43.5	63.0	84.8
November 23	24.0	26.0	34.0	51.5	71.2
December 1	23.0	24.0	33.5	61.5	70.9
December 7	23.0	22.5	29.0	82.5	72.6

those of contemporary Holsteins as 3, and intermediate animals as 2 was used. This is essentially the same scoring system that was used in the other two data sets, except that no animals were coded as 4, which reflects the more tropical environment and generally less hair on adult Holstein crosses under these conditions. To validate these subjective scores using a quantitative measurement, an area of the hair coat of about 64 cm^2 just behind the shoulder was clipped using an electric clipper on a sample of 100 cows that had calved at least once and were lactating. Included were 50 F_1 Carora × Holstein (25 HCT 1, 5 HCT 2, and 20 HCT 3) and 50 75% Holstein:25% Carora cows (25 HCT 1, 5 HCT 2, and 20 HCT 3). All cows that were clipped had body condition scores between 2.5 and 3.5 using a 1 to 5 scale, similar to that of the entire population. Hair weight data were analyzed using GLM procedures and a model including fixed effects of breed group (F_1 or 75% Holstein), HCT, and their interaction.

Rectal temperatures were recorded over a 3-d period in March of 1999 between 1022 to 1915 of each day as the cows left the milking parlor. Ambient conditions were collected using the methodology described by Hammond et al. (1996), and THI was calculated. Mean values of THI were similar throughout the day and were similar across each of the 3 d of measurement. Relative humidity never exceeded 60% and frequently was under 50%; however, throughout the period of evaluation, the THI always surpassed 72. Rectal temperatures were measured using a digital thermometer on lactating cows that were at least 45 d into their lactations. For the analysis of these data, an effect due to the combined effect of breed type and HCT was studied. This effect included six categories: Carora (all HCT = 1) and Holstein (all HCT = 3), as well as the additional groups of F_1 or 75% Holstein, both including HCT 1 or 3. The RT data were analyzed using the GLM procedures of SAS using a model that included the effects of the combined breed-type HCT, month of calving, and the continuous effects of age of cow and body condition score. A similar model that did not include the continuous effect of body condition score was used to analyze 305-d milk yield.

Results and Discussion

Mode of Inheritance. Previous observations of Senepol crossbred cattle suggested that a dominant gene might be responsible for the slick hair of Senepol cattle. Of the 28 calves born from Senepol × Hereford or Hereford × Senepol F_1 dams and Angus sires in Trial 1, 12 were coded as slick-haired (HCT 1) and 16 as normal-haired

Table 2. Ambient conditions during Trial 2

Date	Ambient temp, °C	Black globe temperature Shade, °C	No shade, °C	Relative humidity, %	Temp–humidity index
			Preweaning		
July 16, 1997	30.0	30.5	39.5	68.0	80.6
Aug. 14, 1997	36.0	36.0	45.5	60.0	88.2
July 17, 1998	32.0	34.0	38.5	70.0	84.3
Aug. 14, 1998	33.0	34.0	46.5	68.0	85.6
July 16, 1999	32.5	35.0	51.5	53.5	82.1
Aug. 13, 1999	34.5	38.0	55.0	62.5	86.6
July 13, 2000	32.0	32.0	43.0	72.5	84.6
Aug. 10, 2000	32.5	32.5	41.5	66.5	84.6
			Postweaning		
Dec. 4, 1997	26.0	24.0	26.0	76.0	76.1
Mar. 18, 1998	28.5	27.0	30.0	64.5	78.4
Dec. 4, 1998	29.4	29.5	37.8	55.0	78.2
Mar. 25, 1999	27.0	30.0	42.5	49.0	74.2
Dec. 2, 1999	20.0	20.0	39.0	58.5	65.7
Mar. 18, 2000	30.4	32.0	40.0	56.0	79.7

Table 3. Numbers of calves of each hair score type by breed of sire of dam, Trial 2

	Hair score type				
Breed of Sire of Dam	1	2	3	4	Total
Brahman	0	70	47	12	129
Senepol	37	9	24	23	93
Tuli	2	38	98	27	165
Total	39	117	169	62	

Table 5. Distribution of hair coat types (HCT) of the F_1 daughters of five Carora bulls, Trial 3

	Number of daughters by hair coat type		
Bull	HCT 1	HCT 2	HCT 3
A	43	5	2
B	45	2	1
C	49	0	1
D	15	2	13
E	16	0	14

(HCT 2 through 4). This ratio does not differ significantly (X^2 = 0.57, df = 1; P > 0.40) from the 1:1 ratio that would be expected given the assumption that all of the F_1 dams were heterozygous for the dominant *slick hair* gene. A set of 15 Charolais-sired calves from Senepol × Angus F_1 dams born in 1996 was evaluated for HCT in September of that year as part of Trial 2. Seven of these calves were coded 1, four were coded 3, and four as 4, for a 7:8 ratio of slick:normal hair coats. Distribution of hair coat-type scores of Charolais-sired calves born from 1997 through 2000 by breed of dam are shown in Table 3. No calves from Brahman-sired dams were scored as possessing the slick hair (HCT 1) phenotype. Two of 165 calves from Tuli-sired dams were coded as having a slick-haired coat. Each of these was from a different dam. All but three of the Senepol × Angus F_1 dams were HCT 1. No calves with HCT 1 were produced by these three normal-haired cows. After eliminating the calves from these cows (all sired by the same Senepol bull) and adding the 1996 calves, the calves from the Senepol crossbred dams segregated 44 slick:56 normal, a ratio does not differ from a 1:1 ratio (X^2 = 1.44, df = 1; P > 0.20). The pooled χ^2 value for Trials 1 and 2 is 2.01, df = 2 (P > 0.30). These data support the existence of a single, major, dominant gene that is segregating within these Senepol crossbred calves.

In Trial 3, 384 Carora × Holstein F_1 cows and 81 75% Holstein:25% Carora cows were subjectively evaluated for HCT (Table 4) . About 19.5% (75 of 384) of the F_1 cows were evaluated as having the same hair coat type (HCT 3) as Holstein cows. An additional 21 of 384 (5.5%) of the cows scored possessed slightly more hair than the slick-haired animals and were likely normal-haired (HCT 2). This suggests that not all the Carora sires used in this study were homozygous for the *slick hair* gene. In Table 5, HCT information for five Carora bulls with the largest number of scored progeny (from Holstein dams) is shown. Bulls A, B, and C all have 50 or more scored progeny and are likely homozygous for the *slick hair* gene. For bull C, 49 of 50 of his daughters are HCT 1. One daughter was scored as a HCT 3, and could have been incorrectly scored or may been sired by another bull. Bulls A and B have 43 and 45 HCT 1 daughters out of a total of 50 daughters. Again, the small numbers of HCT 2 and 3 could have resulted from difficulty in scoring HCT or incorrect sire information. Alternatively, there could be other genes that influence the expression of the *slick hair* gene. Bulls D and E, on the other hand, clearly were heterozygous for the *slick hair* gene since both have progeny segregating for HCT at a nearly 1:1 ratio. Since some Carora sires still have Brown Swiss grand- or great-grandsires, it is not surprising that heterozygous bulls remain in the population. If the HCT 2 animals are eliminated from the calculations, these data indicate a gene frequency of the *slick hair* gene in Carora cattle of about 0.79, and thus, a gene frequency of its normal allele of 0.21 (**q**). Therefore, it would be expected that a proportion of Carora cattle equal to q^2 (4.4%) would be born with normal hair coats similar to those of the Brown Swiss parental breed. Lactating Carora cows were observed in a large herd in the Carora region of Venezuela with such hair coats and were reported to be born at a frequency of 8% (M. J. Oropeza, personal communication). This percentage of normal-haired calves is higher than that predicted from the gene frequency estimate above, but it should be noted that only a relatively small number of Carora sires were represented in the data set and homozygous sires appeared to sire more progeny than the heterozygous ones. Our estimate of q in the Carora population should be considered an approximation.

Table 4. Distribution of hair coat types (HCT) by breedtype, Trial 3

		Breed Type		
HCT	Carora	Carora × Holstein F_1	75% Holstein: 25% Carora	Holstein
1	9	288	30	0
2	1	21	12	0
3	0	75	39	93
Total	10	384	81	93

The backcross data from the progeny of Holstein sires and Carora × Holstein F_1 dams provide additional support for the hypothesis of a single dominant gene. More than 50% of the 81 75% Holstein:25% Carora cows classified by HCT would have been expected to have normal hair as they were produced by registered Holstein bulls from Carora × Holstein F_1 cows, some of whom would not have been heterozygous for the *slick hair* gene. Less than 50% of the 75% Holstein cows were slick-haired.

Table 6. Rectal temperatures (°C) of Angus and Angus crossbred calves with and without slick hair, Trial 1

		Angus × (Senepol × Hereford)			
Date	Angus	Normal hair	Slick hair	Avg. SE	*P*-value[a]
July 19	39.87	39.63	39.45	0.12	0.25
July 26	39.73	39.59	39.35	0.08	0.03
August 2	40.20	39.98	39.58	0.13	0.02
November 23	39.43	39.15	38.97	0.08	0.10
December 1	39.15	39.05	39.00	0.10	0.71
December 7	39.27	39.03	38.82	0.09	0.04
Multiplier[a]	1.13	0.86	1.01		

[a]Multiplier × average SE will yield the SE for any cell.

If the HCT 2 females are eliminated from the population, the ratio of 31:39 does not significantly (X^2: $P > 0.30$) deviate from 1:1. An explanation for the increased frequency of animals coded with this intermediate or questionable phenotype in the 75% Holstein as opposed to the F_1 cows is not clear. The 75% cows would have been younger and perhaps there are genes that influence the expression of the slick-hair phenotype that are more frequent in Holstein cattle. The slick-hair phenotype, however, has been observed by T. A. Olson in highly upgraded Holstein cattle in Puerto Rico, as well as in progeny of a slick-haired Holstein bull and normal-haired Holstein cows there, which also appear to be segregating in a 1:1 ratio. Cumulative results of these three trials point to the existence of single, major gene, dominant in mode of inheritance, in Senepol and Carora cattle that is responsible for slick hair.

Clipped Hair Weights. Measurements of clipped hair weight were obtained to provide an objective evaluation of the hair coat type scores used in this study. Hair coat type, breed of sire of dam, and year all had significant effects ($P < 0.05$) on clipped hair weight in the Charolais-sired calves produced in Trial 2. Across breeds of sire of dam, clipped hair weights for HCT 1 through 4 were 0.74 ± 0.13, 2.14 ± 0.07, 2.33 ± 0.06, and 2.47 ± 0.09 g, respectively. Within the 25% Senepol calves, calves coded as slick (HCT 1) had much lower ($P < 0.001$) clipped hair weights (0.76 g) than the weights of 2.38, 2.24, and 2.58 g from HCT 2 through 4 calves, respectively. Because the hair weights of those calves with HCT scores of 2 through 4 are so similar, it seems that these cattle should have been categorized as simply slick or nonslick (normal). Thus, in the evaluations of rectal temperatures of the 25% Senepol calves, those calves with HCT scores other than 1 are usually combined. These objective data clearly support the use of the subjective evaluation of the slick phenotype in this research since it is a dramatically different phenotype as evaluated both subjectively (visually) and through the objective measures of the clipped hair weights.

Clipped hair weights from Carora × Holstein F_1 and 75% Holstein:25% Carora cows were obtained as a part of Trial 3. There was no interaction of HCT with percentage Holstein; therefore, separate values for the 50 and 75% Holstein cows will not be presented. The HCT score affected ($P < 0.01$) the weight of clipped hair, with the weight from cows of HCT 1 (slick) being the lowest (0.18 g) and that of the normal-haired cows being highest at 0.50 g. Clipped weights of the intermediate HCT 2 phenotype were intermediate between those of the slick and normal-haired cows. Even after adjusting for area clipped, hair weights for the slick- and normal-haired cattle were both lower in Trial 3 than the values observed for the calves in Trials 1 and 2 in Florida. An

Table 7. Rectal temperatures (RT) and respiration rates (BPM) by hair coat type (HCT) within breedtype, Trial 2

Breed[a]	HCT	RT July, °C	BPM, July	RT August, °C	BPM, August	Adj. weaning wt, kg	Avg. SE
Brahman	2	39.98	42.2	40.11	44.3	246.9	1.27
Brahman	3	40.06	41.1	40.16	46.0	240.3	1.52
Brahman	4	40.24	44.8	40.28	47.9	233.2	2.76
Senepol	1	40.07	43.6	40.08	47.3	222.2	1.69
Senepol	2	40.13	46.2	40.38	49.9	240.0	3.36
Senepol	3	40.21	43.7	40.37	49.0	226.8	2.01
Senepol	4	40.50	53.3	40.50	53.2	225.5	2.10
Tuli	1	39.60	37.7	39.99	41.3	194.2	6.80
Tuli	2	40.07	43.1	40.16	46.6	208.9	1.69
Tuli	3	40.17	44.4	40.20	46.7	212.6	1.10
Tuli	4	40.26	45.4	40.44	50.0	213.7	1.59
Multiplier[b]		0.04	0.87	0.05	.99	2.28	

[a]Breed of sire of dam.
[b]Multiplier × average SE will yield the SE for any cell.

Table 8. Rectal temperatures (RT), respiration rates (BPM), and weaning weights of Senepol-cross calves by hair coat type (HCT), Trial 2

HCT	RT July, °C	BPM, July	RT August, °C	BPM, August	Adj. weaning wt, kg
1	40.02 ± 0.13	44.7 ± 3.0	39.85 ± 0.13	45.1 ± 2.4	222.7 ± 4.4
4[a]	40.28 ± 0.12	48.9 ± 2.6	40.19 ± 0.11	49.0 ± 2.2	229.1 ± 3.6
P-value	0.01	0.04	0.01	0.01	0.26

[a]Hair coat type scores 2 through 4 are combined in this analysis.

explanation of the differences would include age effects, breed (Holstein vs Charolais) effects, and possibly seasonal effects, since the calves in Florida were beginning to grow their fall hair coats at the time of measurement in September.

Rectal Temperatures and Respiration Rates. Rectal temperatures of the Angus-sired calves in Trial 1 on three summer and three fall/winter measurement dates are given in Table 6. Only the effect of breed/hair coat type and the covariates of age of calf and order of working/data collection consistently affected RT. The 12 slick-haired, Angus-sired 25% Senepol calves had the lowest average body temperature during each of the six data collection dates, ranging from a low of 38.82°C on December 7 to a high of 39.58°C on August 2. The RT of Angus-sired 25% Senepol calves with "normal" hair coats were not different ($P > 0.15$) from those of Angus calves on each of the summer measurements, but were lower ($P < 0.05$) on one of the three fall/winter measurements (November 23) and approached significance ($P < 0.11$) on a second date (December 7). The RT of the slick calves were always lower than those of their normal-coated counterparts with the same breed composition and were significantly so ($P < 0.05$) on two of the three summer evaluations and one of the three fall/winter sessions. The effect of breed/hair coat type on respiration rate was not significant for any date.

The data for RT and BPM by HCT within breeds of dam in Trial 2 are shown in Table 7. The effect of HCT on RT across breeds was highly significant in both July and August as well as on BPM in July (Table 7). The clear indication was that higher quantities of hair caused higher RT. The effect of HCT on BPM was not consistent as it was highly significant in the July measurements, but not ($P > 0.10$) in the August dates. Calves with HCT 4 from Senepol-sired dams had higher BPM ($P < 0.05$) than any other group in July, but differences among other breed-group/HCT combinations generally were not significant.

The RT and BPM data from percentage Senepol calves in which the *slick hair* gene seems to be segregating showed that animals with HCT 1 showed lower RT ($P < 0.01$) and BPM ($P < 0.05$) than normal-haired animals (HCT 2 through 4) in both the July and August collection dates (Table 8). The difference in RT between the slick and nonslick groups was 0.26°C in July and 0.34°C in August. The lower BPM of the slick-haired calves corresponded to their lower RT.

Rectal temperatures and BPM of 25% Senepol heifers by HCT are shown in Table 9; there were no differences in RT and BPM ($P > 0.05$) due to HCT in either December or March. It should be noted, however, that on none of the six dates on which these postweaning data were recorded, did THI value exceed 80. Respiration rates (BPM) of slick-haired heifers tended to be lower ($P < 0.08$) than those of normal-haired heifers during the December measurements.

The RT of Holstein × Carora crossbred cows from Trial 3 that are shown in Table 10 do not indicate that they were under significant heat stress. The relatively low RT could have been due to low humidity in this location. In spite of this apparent lack of heat stress, the combined effects of breed type, HCT, month of calving, and the continuous effects of age in days and body condition score all affected ($P < 0.001$) RT. These data showed a dramatic effect of HCT 1 on RT. The breed types of cattle in this study with HCT 1, Carora, slick F_1, and slick 75% Holstein cows did not differ in RT and all had RT that were lower ($P < 0.001$) than those of any group with normal hair. Within cattle of the same breed composition (F_1 and 75% Holstein), the RT of slick-haired cattle were 0.50 and 0.73°C lower than those of their normal-haired contemporaries. This latter advantage is higher than that observed for the effect

Table 9. Rectal temperatures (RT) and respiration rates (BPM) of Senepol-cross heifers (postweaning , Trial 2

		December		March	
Hair coat type	n	RT	BPM	RT	BPM
1	14	39.64 ± 0.14	37.7 ± 2.3	39.39 ± 0.06	39.1 ± 1.5
4[a]	15	39.78 ± 0.14	43.8 ± 2.2	39.47 ± 0.07	38.8 ± 1.5
P-value		.40	0.06	0.27	0.92

[a]Hair coat types 2 through 4 (normal) are combined in this category.

Table 10. Rectal temperatures (RT) and 305-d milk yield of cows in Venezuela by breed type and hair coat type (HCT), Trial 3

Breed type	n	HCT[a]	RT, °C	305-d milk yield, kg
Carora	9	1	38.44 ± 0.16[bc]	4,560 ± 460[b]
F_1	288	1	38.41 ± 0.03[b]	5,526 ± 87[c]
F_1	75	3	38.91 ± 0.06[d]	5,115 ± 165[bd]
75% Holstein	30	1	38.58 ± 0.09[c]	6,389 ± 250[e]
75% Holstein	39	3	39.31 ± 0.08[e]	5,579 ± 225[cdf]
Holstein	93	3	39.09 ± 0.06[de]	6,104 ± 159[ef]

[a]Hair coat type 2 individuals are not included as their genotype was in doubt.
[b,c,d,e,f]Means with common superscripts do not differ ($P > 0.05$).

of HCT in previous trials and the RT of the normal-haired 75% Holsteins was higher ($P < 0.05$) than even that of the purebred Holsteins. However, the reduction of the RT of slick-haired 75% Holstein relative to that of the Holsteins (–0.51°C) was almost identical to that of the slick-haired F_1 cows over their normal-haired contemporary F_1 cows (–0.50°C).

Differences in RT due to slick vs normal hair coats varied by trial in our study, but could be as much as 0.5°C, similar to that observed elsewhere between *Bos indicus* (50% or more) and *Bos taurus* cattle (Turner, 1982, 1984). Frisch (1981) reported a similar lowered RT (–0.51°C) for Hereford × Shorthorn cattle selected for heat tolerance compared to unselected animals of the same breed composition. The factors responsible for this reduction in temperature are not completely clear. A shorter hair coat is surely responsible in part, as our previous research (Hammond and Olson, 1994) has shown that clipped Hereford calves maintained lower RT. They were not, however, as low as those of Senepol calves. Previous studies in Australia demonstrated that, under heat stress, sleek, dense coats are associated with low body temperatures and high growth rates whereas deep, woolly ones are associated with high body temperatures and low growth rates (Turner and Schleger, 1960; Peters et al., 1982). This relationship apparently results from a dense flat coat being able to provide greater resistance to heat transfer to the skin and its smooth surface being able to reflect more radiation (Hutchinson and Brown, 1969).

Weight Traits. Slick-haired, Angus-sired calves from Trial 1 were heavier ($P < 0.02$) than their normal-haired counterparts at the end of the trial, as they gained over 13 kg more than the normal-haired calves from July 19 to December 7 (Table 11). Slick-haired calves also were heavier ($P < 0.001$) than the Angus calves throughout the evaluation period, but this comparison is confounded with heterosis and breed effects as well as hair coat differences. The weight advantage of the slick-haired calves over Angus increased throughout late summer and fall as it did over the normal-haired crossbred calves of the same breed composition. The greater heat tolerance of the slick-haired calves may have resulted in increased grazing time during this period, as September and October remain warm in central Florida.

There was no effect of HCT within breed of dam on weaning weight ($P > 0.10$) in spite of the fact that RT increased in the calves with greater quantities of hair (Table 7). It should be noted, however, that all of these calves were nursed by cows that were previously shown to be heat tolerant (Hammond et al; 1998). Within calves of Senepol-sired dams, there was no advantage in increased weaning weight for the slick-haired calves, which did not differ ($P > 0.10$) from those of the normal-haired calves (Table 8).

Postweaning weights of the Charolais-sired heifers in Trial 2 by HCT within breed are shown in Table 12. Weights were collected in December, March, June, and again in the following September. Brahman-sired heifers were heavier than the Senepol ($P < 0.02$) and Tuli-sired ($P < 0 .001$) heifers throughout the postweaning period. Hair coat type also generally affected weight, with HCT 4 individuals generally being lighter than

Table 11. Weights (kg) of calves by breed/hair coat score, Trial 1[a]

Date	Angus	Normal-coated A × (S × H)[b]	Slick-coated A × (S × H)	Avg. Se	P-value[a]
July 19	150.5	185.2	195.0	6.0	0.22
August 2	158.7	193.2	205.8	6.4	0.14
November 23	208.0	251.2	276.3	7.5	0.01
December 7	211.9	253.9	277.6	7.2	0.02
Multiplier[c]	1.13	0.88	1.00		

[a]Comparison of the crossbred calves with or without slick hair.
[b]A = Angus, S = Senepol, H = Holstein.
[c]Multiplier × average SE will yield the SE for any cell.

Table 12. Postweaning weights of Charolais-crossbred heifers by breed of sire of dam and hair coat type, Trial 2

Breed[a]	Hair coat	n	Weaning	December	March	June	September	Avg. SE
Brahman	2	33	270.6	278.5	282.7	338.6	394.0	5.0
Brahman	3	19	262.5	266.6	273.0	327.2	376.9	7.0
Brahman	4	3	264.3	273.5	285.0	349.2	412.5	14.4
Senepol	1	14	227.0	242.0	246.5	300.7	360.6	9.1
Senepol	2	2	273.4	279.4	295.4	347.8	398.3	16.6
Senepol	3	8	254.6	262.4	273.8	331.8	395.2	10.8
Senepol	4	5	211.5	217.0	224.1	277.6	337.9	12.8
Tuli	1	2	212.5	228.0	227.9	312.6	351.8	20.3
Tuli	2	11	239.1	250.2	269.9	312.1	368.6	9.1
Tuli	3	35	230.3	241.5	249.5	302.8	358.7	4.7
Tuli	4	19	226.9	236.4	243.4	297.1	342.9	8.3
Multiplier[b]			0.91	0.90	0.98	1.07	1.13	

[a]Breed indicates breed of sire of dam.
[b]Multiplier × average SE will yield the SE for any cell.

those of heifers with shorter hair coats. Postweaning growth of slick- vs normal-haired 25% Senepol heifers is given in Table 13. For the approximately 12-mo period from weaning until the following September, the total growth of these two groups of heifers was essentially equal. Slick-haired heifers gained faster ($P < 0.05$) during the weaning-to-December (fall) period, as had the slick-haired Angus-sired calves in Trial 1. Normal-haired, 25% Senepol heifers, however, tended to gain faster ($P < 0.08$) during the winter months of December to March. For the other two periods, March through June and June through September, weight gains were very similar. These data suggest that the level of heat stress on nonlactating heifers, just as in the calves prior to weaning, may not be sufficient to affect growth rate under pasture conditions at this location. In both Trials 1 and 2, however, slick-haired calves had greater gains than normal-haired calves from weaning until December. This improved gain could be the result of increased grazing activity of the slick-haired calves during this period of some heat stress in Florida.

Postweaning gain and carcass information of 25% Senepol steers is shown in Table 14. It could be hypothesized that HCT 1 (slick) steer calves within the Senepol crossbred animals would have slower growth rates during the winter feeding period due to reduced cold tolerance. The price discounts that such calves receive from order buyers in the fall are believed to be due to the expectation of poorer cold weather growth of such calves. Slick- and normal-haired steers had similar initial weights, gained at similar rates, and ended the feeding period at almost identical weights. The only trait for which there tended to be a difference between the slick- and normal-haired cattle was marbling score ($P < 0.06$). Mean marbling score for slick-haired calves was 532, which corresponds to a quality grade of Low Choice, whereas that of normal-haired steers of the same breed composition was approximately a one-half of a marbling score lower at 477, which corresponds to High Select. Because there were only 12 slick-haired steers in this study, this result should simply raise interest in future evaluation to determine if there truly is a correlation between the slick hair condition and marbling, and if so, to try to ascertain whether the connection is due to a link between the *slick hair* gene and marbling genes or due to some pleiotropic effect of the *slick hair* gene. Calves were valued at weaning by local order buyers and, despite having similar weights, slick-haired calves were discounted an average of \$0.12/kg from the price quoted for normal-haired calves from Senepol crossbred dams. Data from these steer calves seem to indicate that this discount, widely suffered by commercial cattlemen that sell slick-haired Senepol-crossbred calves, is not justifiable.

The lower RT of cattle with slick hair observed in these studies did not have a major effect on growth

Table 13. Total gain (kg) by season of Senepol-cross heifers (postweaning) by hair coat type, Trial 2

HCT	n	Fall[a]	Winter[b]	Spring[c]	Summer[d]	Total
1	14	14.2 ± 2.3	3.8 ± 2.9	54.8 ± 2.5	60.3 ± 3.6	133.0 ± 6.2
4[e]	15	7.2 ± 2.2	11.3 ± 2.7	54.9 ± 2.4	59.6 ± 3.4	133.1 ± 6.0
P-value	0.04	0.07	0.97	0.89	0.99	

[a]Weaning through early December.
[b]December through March.
[c]March through June.
[d]June through September.
[e]Hair coat type 2 through 4 (normal) are combined in this category.

Table 14. Senepol-cross steer postweaning growth and carcass data, Trial 2

HCT	n	Inital feedlot wt	Midterm wt	Winter gain	Final wt	Spring gain	Marbling score[a]	FOE, cm[b]	REA, cm[2c]
1	12	282.2 ± 9.1	396.3 ± 9.1	1.24 ± 0.11	529.9 ± 12.6	1.41 ± 0.10	532 ± 22	0.78 ± 0.09	82.4 ± 1.9
4[d]	22	279.4 ± 6.8	405.2 ± 6.8	1.38 ± 0.08	530.3 ± 9.4	1.35 ± 0.08	477 ± 16	0.87 ± 0.07	84.8 ± 1.4
P-value		0.74	0.44	0.36	0.98	0.68	0.05	0.43	0.32

[a]Marbling scores of 400 to 499 and 500 to 599 result in quality grades of Select and Low Choice, respectively.
[b]FOE = fat over ribeye.
[c]REA = ribeye area.
[d]Hair coat type (HCT) scores 2 through 4 (normal) are combined in this category.

rate of calves to weaning or on postweaning growth of yearlings during warmer seasons of the year. This may be because the effect of high temperature and humidity on such nonlactating animals is insufficient to cause substantial heat stress under our conditions. Finch (1986) reviewed the effects of elevated body temperature on beef cattle and concluded that even small increases could have profound effects on neuroendocrine functions, which could result in reduced fertility, growth, and lactation. Turner (1982) found genetic correlations between RT and measures of female fertility and growth of −0.76 and −0.86, respectively, in beef cattle in Australia. More recently, Burrow (2001) reported favorable genetic correlations between RT and measures of growth and reproduction in Australia. Corroborating this was the observation of T. A. Olson in 1999 that all Carora steers in a pasture in Venezuela were slick-haired. This was in contrast to the milking herd where some Carora cows with normal hair coats were being milked (See Figure 1). When questioned about this, the owner of the largest herd of Carora cattle in Venezuela (M. J. Oropeza, personal communication) stated that bull calves born with normal hair coats in his herd were not retained to be grown out to slaughter weights since Carora steers without slick hair coats did not grow satisfactorily on the pastures of the region.

Milk Yield and Calving Interval. Effect of breed and hair coat type of Holstein × Carora crossbred cows on their 305-d milk yield, whereas not as dramatic as their effect on RT, does indicate an advantage for cattle with slick hair (Table 10). Although the number of records of Carora females is small, it appears their genetic potential for milk yield is lower ($P < 0.05$) than that of Holsteins. Milk yields of both slick and normal-haired F_1 cows were intermediate between those of the parental breeds, but those of the slick-haired cows were higher ($P < 0.03$) than those of normal-haired ones. Milk yield of 75% Holstein cows with slick hair was higher ($P < 0.02$) than that of all other groups except Holstein. The advantage of slick-haired 75% Holstein cows over normal-haired 75% Holstein cows (810 kg) was greater than the difference between the yields of slick and normal-haired F_1 cows (411 kg), just as the differences in RT had been greater in this cross with a greater percentage of Holstein breeding and higher milk yields.

A dominant gene that increased heat tolerance could have a major impact on the dairy industry of the southern U.S. and other parts of the world with warm climates. Although a number of strategies have been developed to alleviate the effects of heat stress on dairy cattle in warm climates, dairy cows continue to suffer from reduced milk yields and pregnancy rates during periods of elevated temperatures. During periods of heat stress, fertility declines due to reduced estrus detection and increased embryo mortality (Hansen and Aréchiga, 1999). It is common for pregnancy rates to drop below 15% in August in well-managed Florida dairies (Drost and Thatcher, 1987). Since the Venezuelan data indicated a somewhat greater advantage in terms of milk yield for HCT 1 cows with a higher percentage of Holstein breeding, we may expect to see a greater effect on milk yield in higher percentage Holsteins. The effect of the *slick hair* gene is also likely to be greater in grazing as opposed to drylot conditions, or in cattle maintained under harsher, more humid, tropical conditions. Hammond and Olson (1994) reported that Senepol cows grazed more than did Hereford cows during daylight hours. Future research is needed to identify the genomic location of this gene as well as the effect of slick hair on milk yield and fertility traits in lactating dairy cows under southern U.S. conditions.

Implications

The identification of a major gene in cattle that reduces the effects of heat stress and its subsequent incorporation into temperate breeds would have a major effect on productivity of cattle in warm climates, particularly fertility of dairy cows through increased embryo survival and greater milk production during periods of heat stress. This trait may become even more important in the dairy industry if environmental regulations force an increase in the use of grazing to reduce the concentration of large numbers of cows in confined areas, and it is of importance in tropical dairies where grazing is extensively utilized. Incorporation of slick hair into temperate *Bos taurus* breeds of beef cattle should allow them to be raised successfully under conditions with greater heat stress than was previously possible. This process of incorporation and use would be facilitated through knowledge of the location and molecular basis of the gene.

Literature Cited

Buffington, D. E., A. Collazo-Arocho, G. H. Canton, D. Pitt, W. W. Thatcher, and R. J. Collier. 1981. Black globe-humidity index (BGHI) as comfort equation for dairy cows. Trans. ASAE (Am. Soc. Agric. Eng.) 24:711–716.

Burrow, H. M.. 2001. Variances and covariances between productive and adaptive traits and temperament in a composite breed of tropical beef cattle. Livest. Prod. Sci. 70:213–233.

Chase, C. C., Jr., A. C. Hammond, and T. A. Olson. 2000. Effect of tropically adapted sire breeds on preweaning growth of F_1 Angus calves and reproductive performance of their Angus dams. J. Anim. Sci. 78:1111–1116.

Drost, M., and W. W. Thatcher. 1987. Heat stress in dairy cows: Its effect on reproduction. Food Anim. Pract. 3:609–617.

Finch, V. A. 1986. Body temperature of beef cattle: Its control and relevance to production in the tropics. J. Anim. Sci. 62:531–542.

Frisch, J. E. 1981. Changes occurring in cattle as a consequence of selection for growth rate in a stressful environment. J. Agric. Sci. 96:23–38.

Hammond, A. C., C. C. Chase Jr., E. J. Bowers, T. A. Olson, and R. D. Randel. 1998. Heat tolerance in Tuli-, Senepol-, Brahman-sired F_1 Angus heifers in Florida. J. Anim. Sci. 76:1568–1577.

Hammond, A. C., and T. A. Olson. 1994. Rectal temperature and grazing time in selected beef cattle breeds under tropical summer conditions in subtropical Florida. Trop. Agric. (Trinidad) 71:128–134.

Hammond, A. C., T. A. Olson, C. C. Chase Jr., E. J. Bowers, R. D. Randel, C. N. Murphy, D. W. Vogt, and A. Tewolde. 1996. Heat tolerance in two tropically adapted *Bos taurus* breeds, Senepol and Romosinuano, compared with Brahman, Angus, and Hereford cattle in Florida. J. Anim. Sci. 74:295–303.

Hansen, P. J., and C. F. Aréchiga.1999. Strategies for managing reproduction in the heat-stressed dairy cow. J. Dairy Sci. 82:36–50.

Hertig, B. A. 1968. Measurement of the physical environment. Page 324 in Adaptation of Domestic Animals. E.S.E. Hafez, ed. Lea & Febiger, Philadelphia, PA.

Hutchinson, J. C. D., and G. D. Brown. 1969. Penetrance of cattle coats by radiation. J. Appl. Physiol. 26:454–462.

Mackinnon, M. J., K. Meyer, and D. J. S. Hetzel. 1991. Genetic variation and covariation for growth, parasite resistance and heat tolerance in tropical cattle. Livest. Prod. Sci. 27:105–122.

Peters, K. J., P. Horst, and H. H. Kleinheisterkamp. 1982. The importance of coat colour and type as indicators of productive adaptability of beef cattle in a subtropical environment. Trop. Anim. Prod. 7:296–304.

Turner, H. G. 1982. Genetic variation of rectal temperature in cows and its relationship to fertility. Anim. Prod. 35:401–412.

Turner, H. G. 1984. Variation in rectal temperature of cattle in a tropical environment and its relation to growth rate. Anim. Prod. 38:417–427.

Turner, H. G., and A. V. Schleger. 1960. The significance of coat type in cattle. Aust. J. Agric. Res. 11:645–655.

West, J. W. 1994. Interactions of energy and bovine somatotropin with heat stress. J. Dairy Sci. 77:2091–2102.